

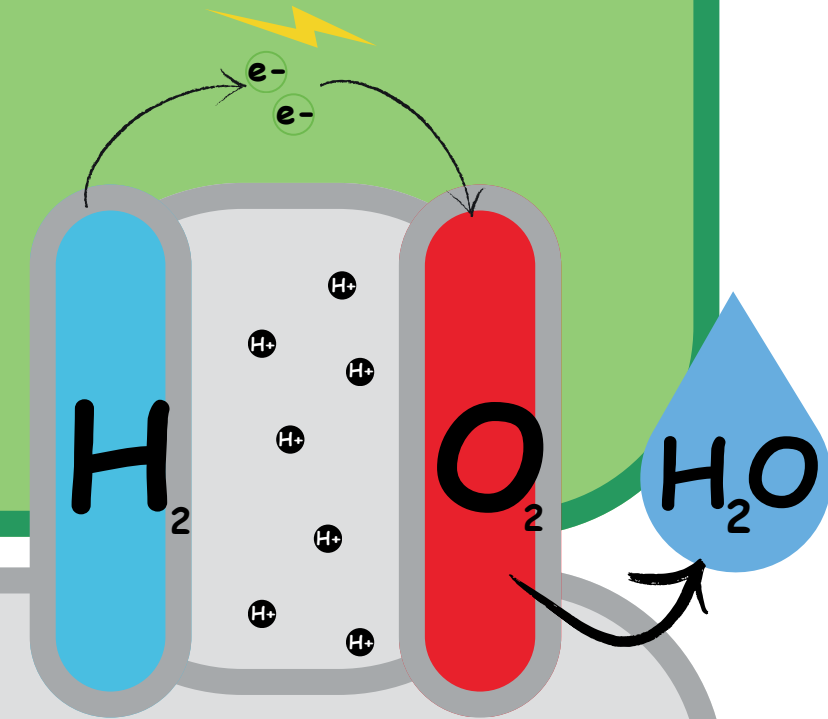
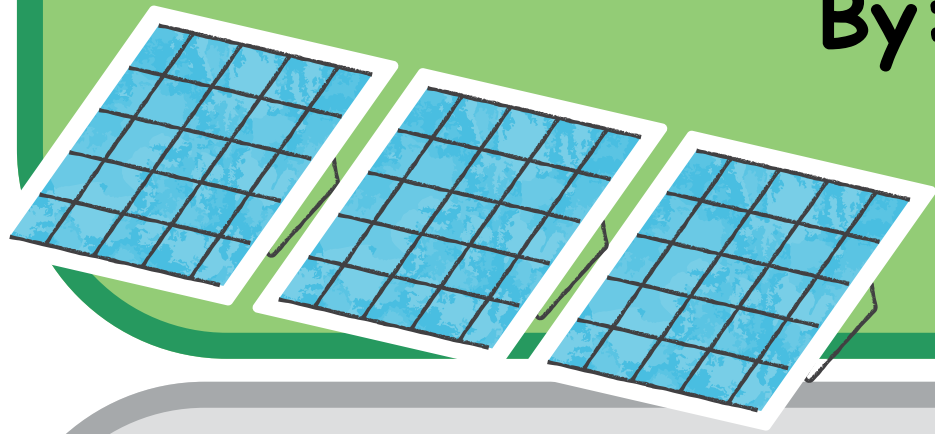
Self sufficient solar- and hydrogen powered house

TRA275 Fuel Cell Systems

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Introduction and Aim

To reach a fossil free society we need to transition to more clean forms of energy. But, with big variations in production of solar and wind power it gets hard to rely on only those electricity sources. One way to overcome this issue is to use excess electricity to produce and store hydrogen, then use a fuel cell to convert that stored energy to electricity again when demand is higher.

The aim of this project is to model such a system for a house so that it can be self sufficient on its solar generated energy, all year round, for the lowest possible cost.

Methodology

By finding approximate prices for the necessary components and realistic efficiency coefficients for each component, an optimization model could be created in python. The main objective for this model was to minimize cost, then constraints were set to control the system. For example we wanted to make sure that there was always enough hydrogen stored to manage the electricity loads, especially during the winter when electricity production from solar is the lowest. More information about how the system was modeled can be read in box "House design". To determine the sizing of each component, a dataset, containing temperatures and electricity load for each hour on a full year, was used.

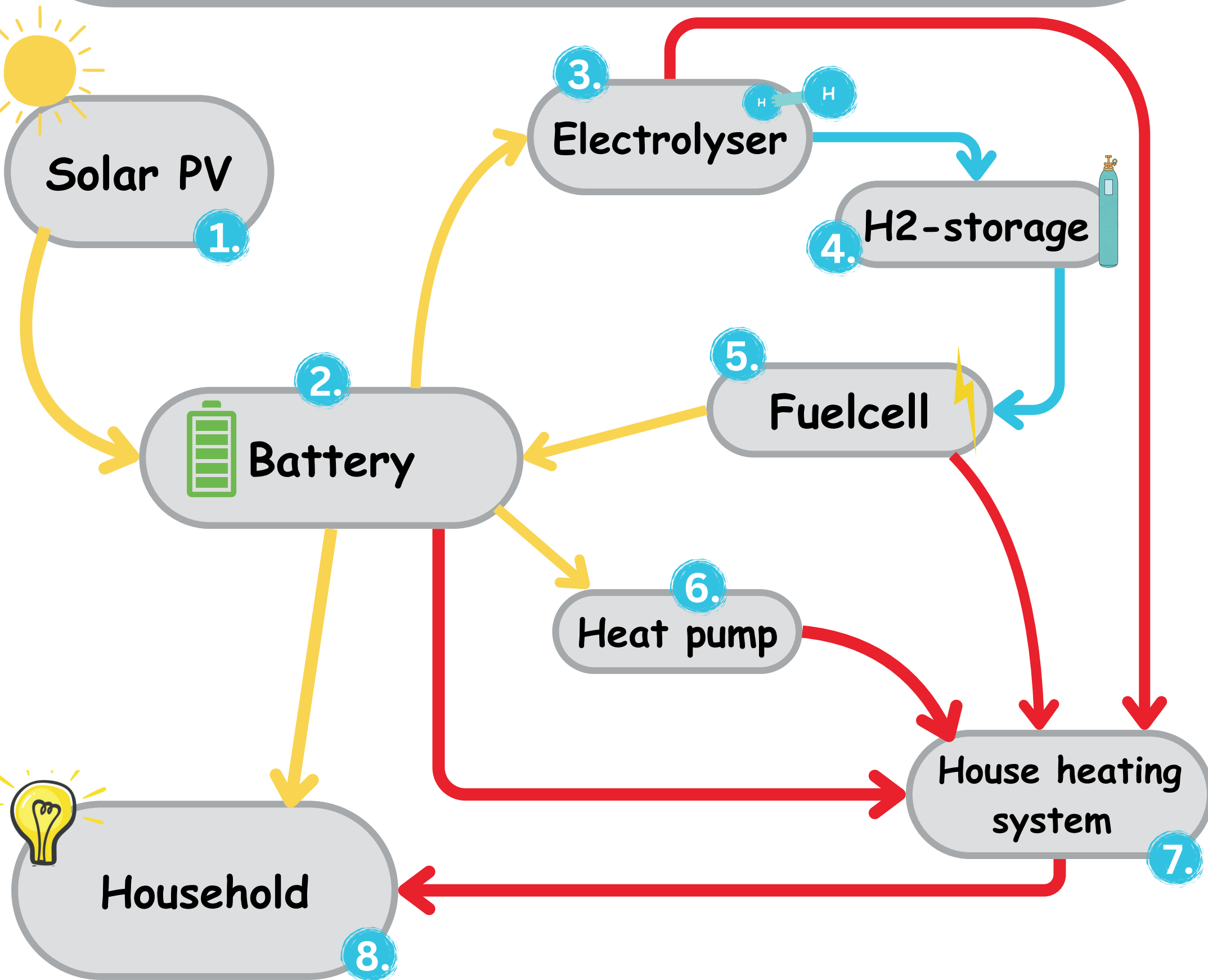
Two models were made. The first model was a simpler ideal system with no losses in any component and did not include heat demand and heat recovery. The second model included efficiencies and recovered the heat losses from the components, also this model was ideal in the sense that all losses were assumed to contribute to the heating of the house.

Estimations/assumptions:

Component	Efficiency [-]	Investment cost [SEK/kW] or [SEK/kWh] if marked by *
Solar PV	1	10 000
Electrolyser	0.8	25 000
Fuel cell	0.5	15 000
Battery	0.9 or 0.95 (charge/discharge)	*8000
H2-storage	-	*200
Heat pump	4 (COP)	3000

Table 1: System components, their efficiencies and installation costs. For each component except the battery and the H2-storage is the cost for capacity per kW electricity consumed/produced. Efficiencies taken from interview with Hans-Olof Nilsson and windandsun.co.uk. Costs are gathered from sesol invoice, energinyheter.se, fuelcellshop.com, goldmansachs.com and elbilen.se

For the second model we added heat demand to our set of data, based on the outdoor temperatures from our original dataset. We assumed no heating was needed when the outside temperature was 15°C or higher, and for temperatures lower than this we assumed a heat loss coefficient of 150 W/K. This means that for every unit of difference between 15°C and the outdoor temperature, 150 W heat was lost. This value was derived from the assumption that the house is a single story building of 130 m², 2.5 m tall, quadratic shape and a mean U-value of 0.4 W/m²K (highest value for new housing from Boverket.se).



House design

This project has modelled and dimensioned an off-grid house relying solely on power from direct and stored solar energy. It is largely inspired by the design of Hans-Olof Nilssons house in Angered, Gothenburg. The flowchart above shows the powerflow for our modelled energy system. Yellow arrows symbolise electricity, red arrows heat and blue arrows hydrogen. It works like this:

Solar PV's (1.) produce power which is used to charge a battery (2.). This battery is used to power the household (8.) every hour. When load is lower than solar input the net energy stored in the battery will increase. The battery will eventually not be able to store all the incoming solar power and that is when the electrolyser (3.) will start operating, converting the electric energy into chemical energy in hydrogen gas, which is compressed and stored in tanks (4.). When the solar power input is lower than the demand of the house, the net energy in the battery will decrease instead. That is when a fuel cell (5.) will start operating to compensate for the missing power required to keep stable battery levels, utilizing the stored hydrogen as fuel. To summarize, the solar cells and and fuel cell are battery chargers, the battery powers everything power consuming in the house and when there is excess energy from solar, the battery also powers the electrolyser which produces hydrogen for later use.

The components are not ideal and all have efficiencies that produce some heat losses. These losses can be utilised to satisfy hot water and house heating demand. This system stores the heat from the electrolyser (20% heat loss), fuel cell (50% heat loss) and battery (5-10% heat loss) in a house heating system (7.). When the heat losses from the components is not enough to satisfy demand, a heat pump (6.) will start operating, powered by the battery.

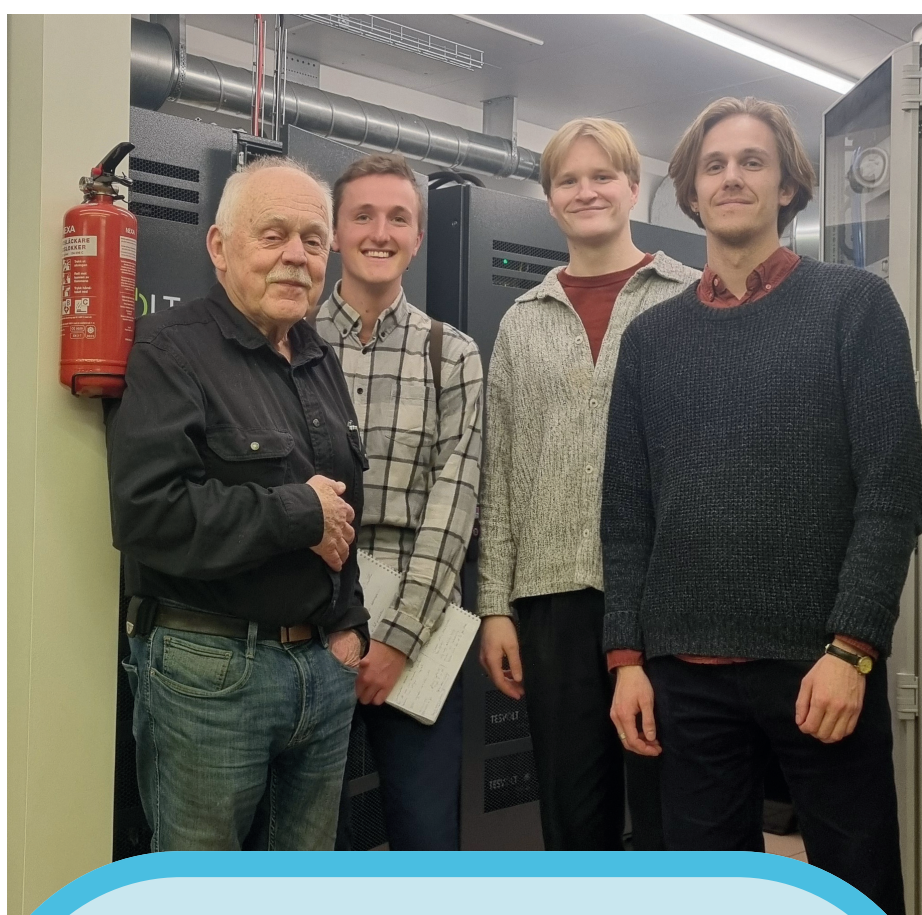
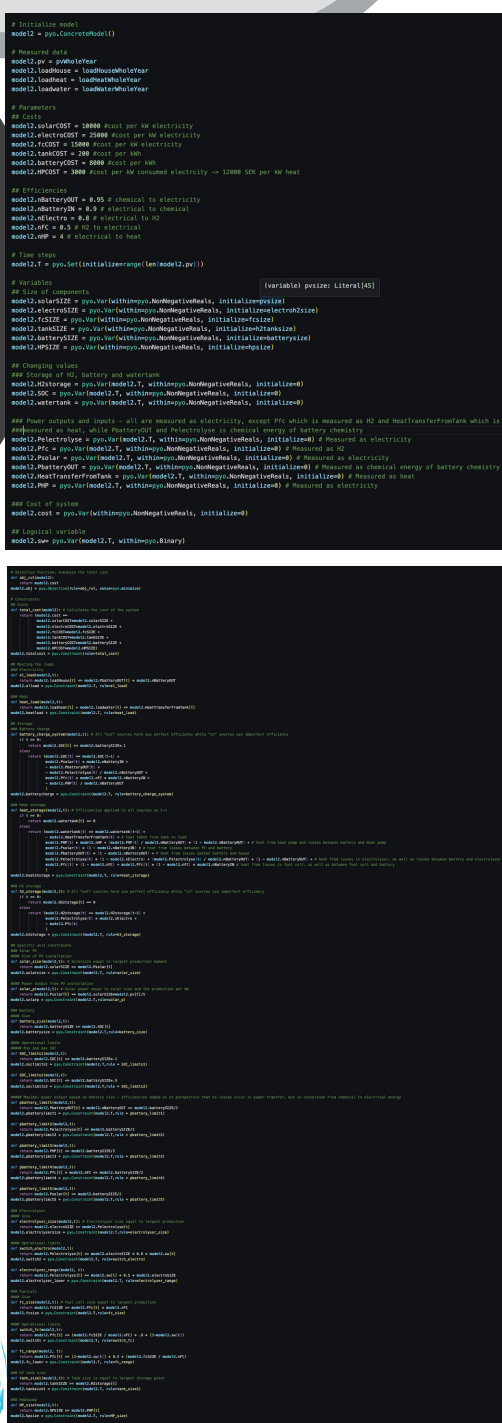
Results from model 1:

Component	Size	Investment cost [SEK]
Solarcell	35 kW	350 000
Electrolyser	4 kW	100 000
Fuel cell	5 kW	75 000
Battery	22 kWh	176 000
H2-storage	5793 kWh	1 158 600

Results from model 2:

Component	Size	Investment cost
Solarcell	65 kW	650 000
Electrolyser	4 kW	100 000
Fuel cell	4 kW	60 000
Battery	121	968 000
H2-storage	10900 kWh	2 180 000
Heat pump	0.2 (electricity) / 0.8 (heat)	600

To the right is the model, programmed in python using the pyomo library. First part is defining variables and setting values. The second part is setting constraints for the model.



This is a picture from our field visit to Hans-Olof Nilsson in Angered. He is a very influential hydrogen pioneer and the first in Sweden to have a self sustaining house that uses hydrogen as energy storage in combination with batteries. All energy used in his house has been produced with by his own solar PV system. His energy system has been running since 2015 and the only thing he changed so far was the batteries. Our model was highly inspired by his system design.

Result & Discussion:

When evaluating if these numbers are reasonable, a lot of comparisons have been made to the system designed and operated by electrical engineer, Hans-Olof Nilsson (see blue box to the left).

Model 1 provided a total investment cost of 1 859 600 SEK. This is a not too far-fetched cost, as Nilsson invested about 2.5 MSEK in his system, which includes more components than this simple system.

The lower cost can also be due to not including a heating load and a heating system. What is most remarkable compared to Nilsson's house is the size of the battery, which is about a quarter of the battery system in the house in Angered. Meanwhile the solar PV system of the model is almost twice as large as of that in Angered. The "low" capacity for the electrolyser and fuel cell (<5kW) is almost identical to Nilsson's system. These components are most likely not bigger because of their high cost.

Model 2 provided a total investment cost of 3 958 600 SEK, about 2M SEK more than that of model 1.

The increase in cost is not surprising considering the implementation of losses. These losses result in that more electricity has to be produced in order to meet the demand over the year. What is interesting is that very little costs seem to be directly attributed to the addition of the house's heat load. The heat pump is extremely small (and cheap), instead must the majority of the heat demand be covered by the heat recovered from the other components. This is of course partly due to our simplified assumption that all the heat losses can be utilized in the heating system, which is not the real case.

However, it could also be interpreted as an indication of that a house fueled by solar power and a hydrogen system may not be in need of an extra large system only for heating, if the heat losses are properly utilised. The solar PV system, battery and hydrogen storage grew a lot compared to model 1, while the electrolyser and fuel cell were kept at similar dimensions. This is likely due to that the losses primarily results in a greater need for energy storage as more energy is required when a lot is lost before being utilised as electricity.

Conclusion:

The second model should not be seen as a complete model for optimizing an off-grid solution. Many results were similar to the system designed by Hans-Olof Nilsson, which we know have been formed by his expert competence. By adding a few more constraints, taking a more realistic heat recovery system into account, and more up-to-date data on loads and investment costs the model could provide more reliable results. Based on this, we believe that this model could be refined into a working model for optimizing off-grid solutions.



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